1.1 Risk-Based PRGs for Fish/Shellfish Tissue

Risk-based preliminary remediation goals (PRGs) are calculated for fish/shellfish tissue and for sediment. Tissue concentrations were calculated as they represent a direct exposure point for human receptors, and because target tissue concentrations are needed to derive sediment concentrations using either sediment-tissue relationships – as either a biota-sediment accumulation regression relationship (BSAR) or biota-sediment accumulation factor BSAF), or the Arnot and Gobas Food Web Model as refined for Portland Harbor (Windward, 2009).

1.1.1 Risk-Based Tissue PRGs for Direct Consumption

Risk-based tissue PRGs associated with consumption of fish and shellfish were calculated using the following equations, adapted from Section 3.5.5 of the Final BHHRA (Kennedy/Jenks, 2013):

Non-cancer effects:

$$Conc_{tissue} = \frac{THQ \times BW \times AT}{ED \times EF \times \dfrac{1}{RfD} \times CR \times CF}$$

Carcinogenic effects:

$$Conc_{tissue} = \frac{TR \times BW \times AT}{ED \times EF \times CSF \times CR \times CF}$$

Combined child and adult exposure was evaluated consistent with the following equation:

$$Conc_{tissue} = \frac{TR \times AT}{EF \times CR_{adj} \times CSF \times CF}$$

where:

$$IR_{t-adj} = \frac{ED_c \times IR_c}{BW_c} + \frac{ED_a \times IR_a}{BW_a}$$

and:

$Conc_{tissue}$ = concentration in fish tissue (µg/kg, wet-weight basis)
IR_c = consumption rate of fish – child (g/day, wet-weight basis)
IR_a = consumption rate of fish – adult (g/day, wet-weight basis)
EF   = Exposure frequency (days/year)
ED_c = Exposure duration – child (years)
ED_a = Exposure duration – adult (years)
BW_c = Body weight – child (kg)

$$BW_a \quad = \quad \text{Body weight – adult (kg)}$$
$$AT \quad = \quad \text{Averaging time (days)}$$

The exposure assumptions used to estimate exposure from fish and shellfish consumption are presented in Table 3-24 of the Final BHHRA.

1.1.2 Risk-Based Tissue PRGs due to Infant Consumption of Human Milk

Risk-based PRGs in fish and shellfish tissue were calculated using the following equation adapted from Section 3.5.6 of the Final Portland Harbor BHHRA:

$$Conc_{fish}\ (\mu g/kg) = \frac{\left(\dfrac{THQ \times BW_{inf} \times AT_{inf} \times RfD}{f_{mbm} \times CR_{milk} \times ED_{inf}}\right) \times \left[\ln(2) \times f_{fm}\right] \times BW_a \times AT_m}{\left(h \times f_f\right) \times EF_a \times ED_a \times 10^{-3}\,kg\,/\,g \times 10^{-3}\,mg\,/\,\mu g \times AE \times CR_{fish}}$$

where:

THQ	=	target hazard quotient
RfD	=	reference dose (mg/kg-day)
AE	=	absorption efficiency of the chemical
h	=	biological half-life of chemical (days)
f_f	=	fraction of absorbed chemical stored in fat
f_{fm}	=	fraction of mother's weight that is fat
f_{mbm}	=	fraction of fat in breast milk
CR_{milk}	=	infant consumption rate of breast milk (kg/day)
CR	=	maternal consumption rate of fish (g/day)
ED_{inf}	=	exposure duration of breastfeeding infant (days)
EF_a	=	exposure frequency – adult (maternal exposure, days/yr)
ED_a	=	exposure duration – adult (days)
BW_{inf}	=	average infant body weight (kg)
BW_a	=	body weight – adult (maternal body weight, kg)
AT_{inf}	=	averaging time – infant exposure (days)
AT_m	=	averaging time – maternal exposure (days)

1.1.3 Incidental Ingestion of Sediment

Risk-based PRGs associated with the incidental ingestion of sediment were calculated using the following equations adapted from Section 3.5.1 of the Final BHHRA:

Noncancer effects:

$$Conc_{sed} = \frac{THQ \times BW \times AT}{EF \times ED \times \dfrac{1}{RfD} \times IRS \times CF}$$

Carcinogenic effects:

$$Conc_{sed} = \frac{TR \times BW \times AT}{EF \times ED \times CSF \times IRS \times CF}$$

Risk-based PRGs based on carcinogenic effects, and where exposure was assumed to occur from childhood through adult years were age-weighted using the following equation:

$$Conc_{sed} = \frac{TR \times AT_c}{CSF \times EF \times IFS_{adj} \times CF}$$

where:

$$IFS_{adj} = \frac{ED_c \times IRS_c}{BW_c} + \frac{ED_a \times IRS_a}{BW_a}$$

and:

Conc$_{sed}$ = concentration in soil or sediment (µg/kg or mg/kg)
IFS$_{adj}$ = age-adjusted soil/sediment ingestion factor [(mg-year)/(kg-day)]
IRS$_a$ = adult soil/sediment ingestion rate (mg/day)
IRS$_c$ = child soil/sediment ingestion rate (mg/day)
EF = exposure frequency (days/year)
ED$_a$ = exposure duration – adult (years)
ED$_c$ = exposure duration – child (years)
BW$_a$ = body weight – adult (kg)
BW$_c$ = body weight – child (kg)
AT = averaging time (days)

The following equation was used to calculate risk-based PRGs in sediment for contaminants known to be mutagenic (cPAHs):

$$Conc_{sed} = \frac{TR \times AT}{EF \times CSF \times IFSM_{adj} \times CF}$$

$$IFSM_{adj} = \left(\begin{array}{c} \dfrac{(ED_{0\text{-}2} \times IRS_c) \times 10}{BW_c} + \dfrac{(ED_{2\text{-}6} \times IRS_c) \times 3}{BW_c} + \\[2ex] \dfrac{(ED_{6\text{-}16} \times IRS_a) \times 3}{BW_a} + \dfrac{(ED_{16\text{-}30} \times IRS_a) \times 1}{BW_a} \end{array} \right)$$

where:

Conc_sed = chemical concentration in soil or sediment (mg/kg)
IRS_a = adult soil/sediment ingestion rate (mg/day)
IRS_c = child soil/sediment ingestion rate (mg/day)
EF = exposure frequency (days/year)
ED_{0-2} = exposure duration ages 0-2 (years)
ED_{2-6} = exposure duration ages 2-6 (years)
ED_{6-16} = exposure duration ages 6-16 (years)
ED_{16-30} = exposure duration ages 16-30 (years)
BW_a = adult body weight (kg)
BW_c = child body weight (kg)
AT = averaging time (days)

The exposure assumptions are provided in Tables 3-21 and 3-22 of the Final BHHRA.

1.1.4   Dermal Contact with Sediment

Risk-based PRGs for dermal contact with sediment were calculated using the following equations adapted from Section 3.5.2 of the Final BHHRA:

Non-cancer effects:

$$Conc_{sed} = \frac{THQ \times AT \times BW}{EF \times ED \times \dfrac{1}{RfD} \times SA \times AF \times ABS \times CF}$$

Cancer effects:

$$Conc_{sed} = \frac{TR \times AT_c \times BW}{ED \times ED \times CSF \times SA \times AF \times ABS \times CF}$$

Combined child and adult age-weighted exposures resulting from dermal contact with contaminants in sediment for the recreational beach user exposure scenarios were calculated consistent with the following equations:

where:

$$SFS_{adj} = \frac{ED_c \times AF_c \times SA_c}{BW_c} + \frac{ED_a \times AF_a \times SA_a}{BW_a}$$

and:

Conc_sed = concentration in soil or sediment (µg/kg or mg/kg)

SFS$_{adj}$ =   age-adjusted dermal contact factor [(mg-year)/(kg-day)]
ABS   =   absorption efficiency
SA$_a$ =   exposed skin surface area – adult (square centimeters [cm^2])
SA$_c$ =   exposed skin surface area – child (cm^2)
AF$_a$ =   soil-to-skin adherence factor – adult (mg/cm^2)
AF$_c$ =   soil-to-skin adherence factor – child (mg/cm^2)
EF   =   exposure frequency (days/year)
ED$_a$ =   exposure duration – adult (years)
ED$_c$ =   exposure duration – child (years)
BW$_a$ =   body weight – adult (kg)
BW$_c$ =   body weight –child (kg)
AT   =   averaging time (days)

Risk-based PRGs for cPAHs for dermal exposure to sediments were calculated as:

$$C_s = \frac{TR \times AT}{EF \times CSF \times IFSM_{adj} \times ABS \times CF}$$

$$DFSM_{adj} = \left(\begin{array}{c} \dfrac{ED_{0\text{-}2} \times AF_c \times SA_c \times 10}{BW_c} + \dfrac{ED_{2\text{-}6} \times AF_c \times SA_c \times 3}{BW_c} + \\[2ex] \dfrac{ED_{6\text{-}16} \times AF_a \times SA_a \times 3}{BW_a} + \dfrac{(ED_{16\text{-}30} \times AF_a \times SA_a \times 1)}{BW_a} \end{array} \right)$$

where:

Conc$_{sed}$ =   chemical concentration in soil or sediment (mg/kg)
ABS   =   absorption efficiency
SA$_a$ =   adult exposed skin surface area (square centimeters [cm^2])
SA$_c$ =   child exposed skin surface area (cm^2)
AF$_a$ =   adult soil-to-skin adherence factor (mg/cm^2)
AF$_c$ =   child soil-to-skin adherence factor (mg/cm^2)
EF=   =   exposure frequency (days/year)
ED$_{0\text{-}2}$ =   exposure duration ages 0-2 (years)
ED$_{2\text{-}6}$ =   exposure duration ages 2-6 (years)
ED$_{6\text{-}16}$ =   exposure duration ages 6-16 (years)
ED$_{16\text{-}30}$ =   exposure duration ages 16-30 (years)
BW$_a$ =   adult body weight (kg)
BW$_c$ =   child body weight (kg)
AT   =   averaging time (days)

Exposure assumptions are presented in Tables 3-21 and 3-22 of the Final BHHRA.

The individual pathway-specific calculations are combined to a total risk-based PRG in sediment using the following equation:

$$PRG_{sed} = \cfrac{1}{\cfrac{1}{Conc_{sed} - Ingestion} + \cfrac{1}{Conc_{sed} - dermal}}$$

1.1.5   Calculation of Sediment Risk-Based PRGs for Fish/Shellfish Consumption

Target tissue concentrations were calculated using the method described in Section 1.1.1. To calculate sediment PRGs for scenarios where fish consumption is primarily the fillet, it was necessary to determine the relationship between whole body and fillet-only concentrations, because both the BSAFs/BSARs and the FWM are based on whole body concentrations. The whole-body/fillet concentration ratios were calculated using the measured mean whole body and fillet concentrations of each COC on a river mile or fishing zone basis, and are presented in Table 2.

cPAHs

A BSAR for benzo(a)pyrene in clams was described in the Bioaccumulation Modeling Report (Windward, 2009) using the following equation:

$$\ln(C_{sed}) = \frac{\ln(C_{tiss}) - \ln(CF) + 2.47}{0.60}$$

Because the BSAR is based on lipid-normalized tissue and organic carbon normalized, corrections for site organic carbon and the lipid content of clams were incorporated to arrive at a dry-weight sediment benzo(a)pyrene concentration:

$$\ln(C_{sed-dry\ weight}) = \left[\frac{(\ln(C_{tiss\text{-}wet\ weight}) - \ln(f_{lipid})) - \ln(CF) + 2.47}{0.60}\right] + \ln(f_{oc})$$

and:

$$C_{sed\text{-}wet\ weight} = e^{\left[\frac{(\ln(C_{tiss\text{-}wet\ weight}) - \ln(f_{lipid})) - \ln(CF) + 2.47}{0.60}\right] + \ln(f_{oc})}$$

A target cPAH concentration of 7.1 µg/kg in clams was used based on the central-tendency consumption rate of 3.3 g/day was used to calculate the sediment PRG.

Hexachlorobenzene

Sediment-tissue BSAFs for hexachlorobenzene were developed for large home-range species (brown bullhead, carp, and crappie), no relationship was established for smallmouth bass (Windward, 2009). The general relationship between sediment and tissue concentrations is expressed by the following equation:

$$C_{sed} = \frac{C_{tissue}}{BSAF}$$

Correcting for the organic carbon content of sediment and lipid content of fish gives the following equation:

$$C_{sed} = \frac{\left[\left(\dfrac{C_{tissue}}{f_{lipid}}\right) \times f_{oc}\right]}{BSAF}$$

where:

$Conc_{sed}$	=	chemical concentration in soil or sediment (µg/kg)
f_{lipid}	=	lipid content of fish (percent)
f_{oc}	=	sediment organic carbon content (1.71 percent)
BSAF	=	biota-sediment accumulation factor (unitless)

	BSAF	Lipid Content (percent)
Black Crappie	2.02	5.2
Brown Bullhead	0.295	2.4
Carp	0.244	8.8

As noted above, BSAFs were only developed for large home-range species, and not for smallmouth bass. Accordingly, target sediment concentrations were calculated for each species, and the risk-based sediment PRG for hexachlorobenzene was calculated using the following equation:

$$PRG_{sed} = \frac{1}{\dfrac{1}{Conc_{sed} - Crappie} + \dfrac{1}{Conc_{sed} - Carp} + \dfrac{1}{conc_{sed} - Bullhead}}$$

PRGs Calculated using the Food-Web Model

The Arnot and Gobas food-web model (Windward, 2009) was refined for Portland Harbor, and accounts for uptake of contaminants via direct incidental ingestion, dietary uptake, and uptake of dissolved contaminants via ingestion and gill uptake. The FWM was calibrated for chlorinated persistent organic contaminants (aldrin, dieldrin, chlordane, DDx, PCBs, and dioxins/furans). Although the final BHHRA evaluated consumption of smallmouth bass, carp, brown bullhead, and crappie, the latter two species are not evaluated in the FWM. However, largescale sucker were used as a surrogate for bullhead, and sculpin as a surrogate for crappie, as they were considered representative of the same trophic group (Windward, 2009). In addition, the FWM as

calibrated for 2,3,4,7,8-pentachlorodibenzo furan was assumed to be representative of total dioxins/furans. Oregon human health ambient water quality criteria for consumption of water and organism were used as input for dissolved water concentration (DEQ, 2011).

The calculated whole body concentrations were converted to fillet concentrations using the whole-body/fillet ratios presented in Table 2. The resulting fillet concentration for each of the four species were further combined as a weighted mean, with each species representing 25 percent of the total diet. The goal-seek function in Excel was then used to iteratively calculate an average sediment concentration that resulted in the averaged tissue concentration of the four modeled species.

REFERENCES

Kennedy/Jenks Consultants. 2013. Portland Harbor RI/FS, Final Remedial Investigation Report, Appendix F, Baseline Human Health Risk Assessment. Portland, OR. April 2013.

Oregon Department of Environmental Quality (ODEQ), 2011. Water Quality Standards for Toxic Pollutants, Table 40. OAR 340-041-0033

Windward. 2009. Portland Harbor RI/FS Bioaccumulation Modeling Report. Draft. WE-09-0003. Prepared for the Lower Willamette Group, Portland, OR. Windward Environmental LLC, Seattle, WA. July 21, 2009.

Table 1 Risk-Based Preliminary Remediation Goals In Tissue							
		PRGs (µg/kg fish tissue) Consumption Rate = 142 g/day					
		Cancer	Noncancer		Infant	PRG	Basis[a]
Arsenic		6.7.E-01	7.9.E+01	6.7.E-01		6.7.E-01	ca
Aldrin		5.9.E-02	7.9.E+00	5.9.E-02		5.9.E-02	ca
Dieldrin		6.3.E-02	1.3.E+01	6.3.E-02		6.3.E-02	ca
Chlordane		2.9.E+00	1.3.E+02	2.9.E+00		2.9.E+00	ca
DDx		3.0.E+00	1.3.E+02	3.0.E+00	9.4E+01	3.0.E+00	ca
Hexachlorobenzene		6.3.E-01	2.1.E+02	6.3.E-01		6.3.E-01	ca
cPAHs		4.6.E-02	7.9.E+01	4.6.E-02			ca
PCBs		5.0.E-01	5.2.E+00	5.0.E-01	2.7E-01	2.7.E-01	infant
TCDD		7.7.E-06	1.8.E-04	7.7.E-06	6.2E-06	6.2.E-06	infant
PDBEs			2.6.E+01	2.6.E+01	8.9E-01	8.9.E-01	infant

Table 2				
	Whole body/Fillet Concentration Ratio			
	Smallmouth Bass	**Common Carp**	**Brown Bullhead**	**Black Crappie**
Arsenic	1.19			
Aldrin	5.77	1.36	10.46[a]	12.0[a]
Dieldrin	5.77	1.36	10.46[a]	12.0[a]
Chlordane	5.92	1.40	10.46	12.0
DDx	7.17	1.42	4.06	6.32
Hexachlorobenzene	5.5	1.3	1.3[b]	5.5[b]
cPAHs				
PCBs	8.02	1.82	1.56	5.46
TCDD	6.13	1.52	1.52[b]	6.13[c]
PDBEs				

Notes:

a – Fillet-whole body ratios for chlordane used as surrogate

b – The ratio established for carp was used for brown bullhead

c – The ration established for smallmouth bass was used for crappie